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Subject (Corrosion Engineering) / Code (CES.R.439)
Lecturer (1)
1ˢᵗ/2ⁿᵈ term – Lecture No. & Lecture Name (Form of corrosion)

1

Forms of Corrosion

It is convenient to classify corrosion by the forms in which it manifests itself, the basis for classification being the appearance of corroded metal. Each form can be identified by mere visual observation. In most cases the naked eye is sufficient but sometimes magnification is helpful or required. Valuable information for the solution of a corrosion problem can often be obtained through careful observation of the corroded test specimens or failed equipment. Examination before cleaning is particularly desirable.

Some of the eight forms of corrosion are unique, but all of them are more or less interrelated. The eight forms are:

1- Uniform (or General) attack.

2- Galvanic (or Tow- metal) .

3- Crevice corrosion .

4- Pitting.

5- Filiform corrosion

6- Intergranular corrosion .

7- Erosion corrosion   8- stress corrosion.

9- Corrosion fatigue cracking

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(Chemical Engineering and Petroleum Industries Department)
Class (4ᵗʰ)
Subject (Corrosion Engineering) / Code (CES.R.439)
Lecturer (1)
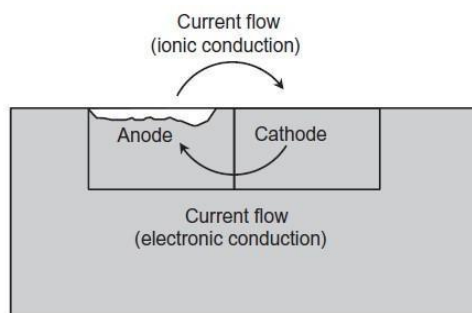**1ˢᵗ/2ⁿᵈ term – Lecture No. & Lecture Name (Form of corrosion)**

Uniform corrosion

It is the uniform thinning of a metal without any localized attack. Corrosion dose not penetrate very deep inside. The most familiar example is the rusting of steel in air.

A uniform, regular removal of metal from the surface is the usually expected mode of corrosion. For uniform corrosion, the corrosion environment must have the same access to all parts of the metal surface, and the metal itself must be metallurgically and compositionally uniform.

Atmospheric corrosion is probably the most prevalent example of uniform corrosion at a visually apparent rate. uniform corrosion is preferred from a technical view point because it is predictable and thus acceptable for design.

Galvanic Corrosion

Galvanic Corrosion occurs when two metals with different electrochemical potentials or with different tendencies to corrode are in metal-to-metal contact in a corrosive electrolyte, i.e. when two dissimilar alloys are coupled in the presence of a corrosive electrolyte one of them is preferentially corroded while the other is protected from corrosion.

Current flow
(ionic conduction)

Anode   Cathode

Current flow
(electronic conduction)

Al-Mustaqbal University / College of Engineering & Technology
(Chemical Engineering and Petroleum Industries Department)
Class (4th)
Subject (Corrosion Engineering) / Code (CES.R.439)
Lecturer (1)
1st/2nd term – Lecture No. & Lecture Name (Form of corrosion)

Description:- when two metals with different potentials are joined ,such as copper(+0.334 v) and iron (-0.44 v) , a galvanic cell is formed. a cell in which the chemical change is the source of energy is called a "**galvanic** **cell**". The corrosion which is caused due to the formation of the galvanic cell, therefore, called "*galvanic corrosion*" . The driving force for corrosion is a potential different between different materials. Between two different materials connected through the electrolyte, the less noble will became the anode and tend to corrode. For example a galvanic corrosion between welded steel and stainless steel. The carbon steel pipe flange is active to the stainless steel pipe, and is corroded preferentially near the weld. Preferential corrosion near the junction between dissimilar alloys is characteristic of galvanic corrosion. the corrosion decreases at points farther from the junction due to higher resistance through a longer electrolyte path.

Factors affecting galvanic corrosion

A- **Position of metals in the galvanic series** as mentioned earlier, the further apart the metals are in the galvanic series, the greater is the chance for galvanic corrosion. The magnitude of galvanic corrosion primarily depends on how much potential difference exists between two metals. For a particular environment, the metals selected should be close to each other in the galvanic series to minimize galvanic corrosion. Active metals should not be joined with passive metals.

B- **The nature of environment**

For instance, water containing copper iron, like seawater, is likely to form galvanic cells on a steel surface of the tank. If the water in contact with steel is either acidic or contains salt, the galvanic reaction is accelerated because of the increased ionization of the electrolyte.

C- **Area, Distance and Geometric effects**. The anode to cathode area ratio is extremely important as the magnitude of galvanic corrosion is seriously affected by it. For a given amount of current, the metal with smallest area has the largest current density, and hence is more damage if corrosion occurs at it. The rate of corrosion increase with the ratio of cathode to anode area.

Al-Mustaqbal University / College of Engineering & Technology
(Chemical Engineering and Petroleum Industries Department)
Class (4ᵗʰ)
Subject (Corrosion Engineering) / Code (CES.R.439)
Lecturer (1)
1ˢᵗ/2ⁿᵈ term – Lecture No. & Lecture Name (Form of corrosion)

Al-Mustaqbal University / College of Engineering & Technology
(Chemical Engineering and Petroleum Industries Department)
Class (4ᵗʰ)
Subject (Corrosion Engineering) / Code (CES.R.439)
Lecturer (1)
1ˢᵗ/2ⁿᵈ term – Lecture No. & Lecture Name (Form of corrosion)

Table 1.5 Standard potential series

Electrode	Reaction	E°_{red} (V)
Li^+, Li	$Li^+ + e^- \rightarrow Li$	−3.024
K^+, K	$K^+ + e^- \rightarrow K$	−2.924
Ca^{2+}, Ca	$Ca^{2+} + 2e^- \rightarrow Ca$	−2.87
Na^+, Na	$Na^+ e^- \rightarrow Na$	−2,714
Mg^{2+}, Mg	$Mg^{2+} + 2e^- \rightarrow Mg$	−2.34
Ti^{2+}, Ti	$Ti^{2+} + 2e^- \rightarrow Ti$	−1.75
Al^{3+}, Al	$Al^{3+} + 3e^- \rightarrow Al$	−1.67
Mn^{2+}, Mn	$Mn^{2+} + 2e^- \rightarrow Mn$	−1.05
Zn^{2+}, Zn	$Zn^{2+} + 2e^- \rightarrow Zn$	−0.761
Cr^{3+}, Cr	$Cr^{3+} + 3e^- \rightarrow Cr$	−0.71
Fe^{2+}, Fe	$Fe^{2+} + 2e^- \rightarrow Fe$	−0.441
Co^{2+}, Co	$Co^{2+} + 2e^- \rightarrow Co$	−0.277
Ni^{2+}, Ni	$Ni^{2+} + 2e^- \rightarrow Ni$	−0.250
Sn^{2+}, Sn	$Sn^{2+} + 2e^- \rightarrow Sn$	−0.140
Pb^{2+}, Pb	$Pb^{2+} + 2e^- \rightarrow Pb$	−0.126
Fe^{3+}, Fe	$Fe^{3+} + 3e^- \rightarrow Fe$	−0.036
H^+, H_2	$2H^+ + 2e^- \rightarrow H_2$	−0,000
Saturated calomel	$Hg_2Cl_2 + 2e^- \rightarrow 2Hg + 2Cl^-$ (Sat. KCl)	0.244
Cu^{2+},Cu	$Cu^{2+} + 2e^- \rightarrow Cu$	0.344
Cu^+,Cu	$Cu^+ + e^- \rightarrow Cu$	0.522
Hg_2^{2+}, Hg	$Hg_2^{2+} + 2e^- \rightarrow 2Hg$	0.798
Ag^+, Hg	$Ag^{2+} + 2e^- \rightarrow 2Hg$	0.799
Pd^+, Pd	$Pd^+ + 2e^- \rightarrow Pd$	0.83
Hg^+, Hg	$Hg^+ + e^- \rightarrow Hg$	0.854
Pt^{2+}, Pt	$Pt^{2+} + 2e^- \rightarrow Pt$	1.2 (ca)
Au^{3+}, Au	$Au^{3+} + 3e^- \rightarrow Au$	1.42
Au^+, Au	$Au^+ + e^- \rightarrow Au$	1.68

CREVICE CORROSION

Crevices are formed at welds, in condensers, and between metal surfaces and valves. This type of corrosion is initiated by small volumes of solution captured in crevices under bolt gasket rivets or surface deposits. It destroys mechanical joint integrity in structures constructed from stainless steel, aluminum, titanium, and copper. In the case of corrosion by dissolved oxygen, activepassive short circuits are formed between the aggressive solution in the crevice, which becomes oxygen depleted (anode), and the external metal surface (cathode). The initiation of crevice corrosion is based on pH decrease in the bottom of the crevice.
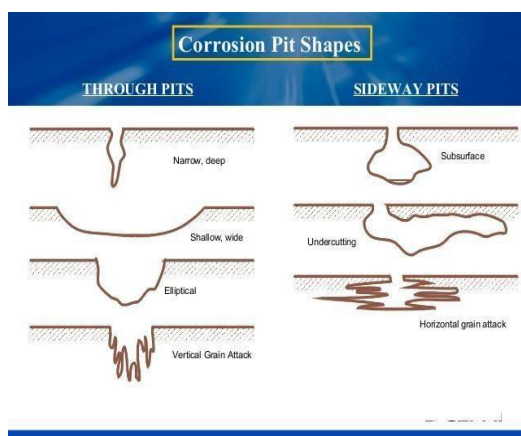
Several steps can be taken to prevent and/or control crevice corrosion:

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(Chemical Engineering and Petroleum Industries Department)
Class (4ᵗʰ)
Subject (Corrosion Engineering) / Code (CES.R.439)
Lecturer (1)
1ˢᵗ/2ⁿᵈ term – Lecture No. & Lecture Name (Form of corrosion)

1.   Proper design, avoiding crevices, will control crevice corrosion. If lap joints are used, the crevices caused by such joints should be closed by either welding or caulking. Welded butt joints are preferable to bolted or riveted joints.

2.   Porous gaskets should be avoided. Use an impervious gasket material. During long shutdown periods, wet packing materials should be removed.

3.   The use of alloys resistant to crevice corrosion should be considered. The resistance of stainless steels to crevice corrosion can be improved by increasing the chromium, nickel, molybdenum,

4.   Reduction of crevice corrosion can be accomplished, when possible, by reducing the temperature, decreasing the chloride content, or decreasing the acidity.

5.   Regular inspections and removal of deposits should be scheduled.

Pitting corrosion

Pitting represents an extremely localized attack that produces holes in the metal or alloy. It is one of the most destructive, localized forms of corrosion. The pits are small cavities or holes with a depth greater than or equal to the surface diameter. They penetrate the metal, causing equipment failure due to preformation with minimal weight loss. The severity of pitting corrosion is controlled by environment, chloride concentration, electrolyte acidity, oxidizer concentration,

Al-Mustaqbal University / College of Engineering & Technology
(Chemical Engineering and Petroleum Industries Department)
Class (4th)
Subject (Corrosion Engineering) / Code (CES.R.439)
Lecturer (1)
1st/2nd term – Lecture No. & Lecture Name (corrosion)

Al-Mustaqbal University / College of Engineering & Technology
(Chemical Engineering and Petroleum Industries Department)
Class (4ᵗʰ)
Subject (Corrosion Engineering) / Code (CES.R.439)
Lecturer (1)
1ˢᵗ/2ⁿᵈ term – Lecture No. & Lecture Name (corrosion)

Pits on after simulated environment

304 stainless steel exposure to marine

Filiform corrosion

Filiform corrosion is observed under thin organic coatings on aluminum, steel, aircraft structures exposed to humid atmosphere, beverage cans, flanges, gaskets, dis-bonded underlying metals coated with organic coatings weld zones, and so forth.
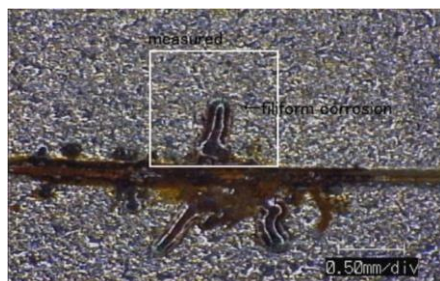
Appearance of filiform corrosion tracks

The line in the center represents the knife-score. The filiform corrosion grew in both directions from the line and is composed of a head and the tail.
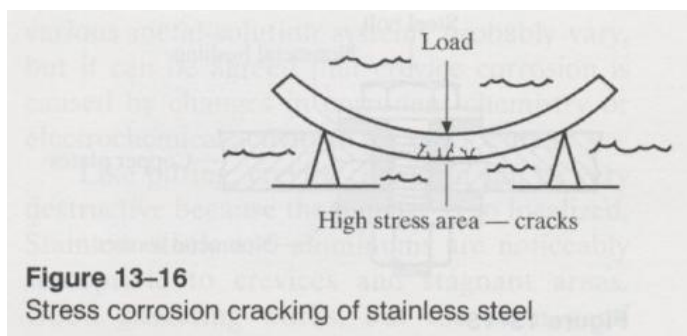
Stress corrosion cracking

Stress corrosion cracking (SCC) is defined as crack growth due to simultaneous tensile stress and corrosive environments on active metals

or alloys. In order for SCC to occur, the metal should be susceptible to SCC and be in a corrosive environment such as chloride ions, water, oxygen, pH, and so on. SCC leads to catastrophic failure

Al-Mustaqbal University / College of Engineering & Technology
(Chemical Engineering and Petroleum Industries Department)
Class (4th)
Subject (Corrosion Engineering) / Code (CES.R.439)
Lecturer (1)
1st/2nd term – Lecture No. & Lecture Name (corrosion)

9

in aircraft structures, nuclear facilities, boilers, and liquid or gas transmission pipes.

Figure 13–16
Stress corrosion cracking of stainless steel

Stress corrosion cracking of austenitic stainless steel

Al-Mustaqbal University / College of Engineering & Technology
(Chemical Engineering and Petroleum Industries Department)
Class (4ᵗʰ)
Subject (Corrosion Engineering) / Code (CES.R.439)
Lecturer (1)
1ˢᵗ/2ⁿᵈ term – Lecture No. & Lecture Name (corrosion)

10

Corrosion fatigue cracking

Fatigue cracking is mechanical degradation (brittle failure) when exposed to corrosion and cycling loading. Corrosion fatigue cracking (CFC) should not be confused with SCC, because the only requirement for CFC is exposure under tensile stress
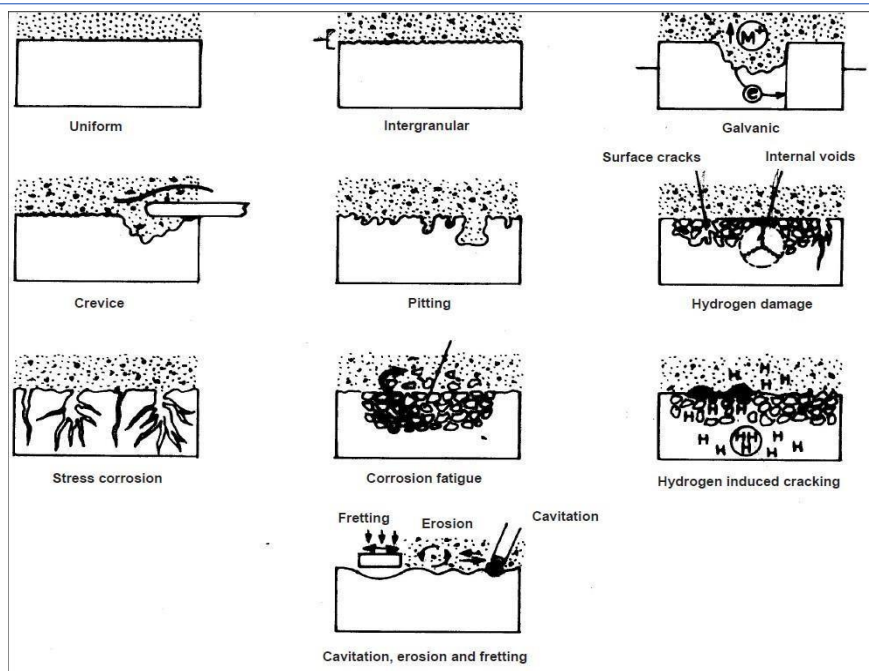
Intergranular Corrosion

Intergranular corrosion is a localized form of corrosion. It is a preferential attack on the grain boundary phases or the zones immediately adjacent to them. Little or no attack is observed on the main body of the grain. This results in the loss of strength and ductility. The attack is often rapid, penetrating deeply into the metal and causing failure.

The factors that contribute to the increased reactivity of the grain boundary area include:

1. Segregation of specific elements or compounds at the grain   boundary, as in aluminum alloys or nickel–chromium alloys

2. Enrichment of one of the alloying elements at the grain boundary,   as in brass

3. Depletion of the corrosion-resisting constituent at the grain boundary, as in stainless steel

All of these factors contributing to intergranular corrosion originate in the thermal processing of materials, such as welding, stress relief, and ther heat treatments.

Al-Mustaqbal University / College of Engineering & Technology
(Chemical Engineering and Petroleum Industries Department)
Class (4ᵗʰ)
Subject (Corrosion Engineering) / Code (CES.R.439)
Lecturer (1)
1ˢᵗ/2ⁿᵈ term – Lecture No. & Lecture Name (corrosion)

11

Types of corrosion

Erosion Corrosion

The term "erosion" applies to deterioration due to mechanical force. When the factors contributing to erosion accelerate the rate of corrosion of a metal, the attack is called "erosion corrosion." Erosion corrosion is usually caused by an aqueous or gaseous corrodent flowing over the metal surface or impinging on it. The mechanical deterioration may be aggravated by the presence of a corrodent, as in the case of fretting or corrosive wear.

Erosion corrosion is affected by *velocity, turbulence, impingement*, presence of suspended solids, temperature, and prevailing cavitation conditions. The acceleration of attack is due to the distribution or removal of the protective surface film by mechanical forces exposing fresh metal surfaces that are anodic to the uneroded neighboring film.

DEFINITION OF ANODE AND CATHODE

A combination of two electrical conductors (electrodes) immersed in an electrolyte is called a galvanic cell in honor of Luigi Galvani, a physician in Bologna, Italy, who published his studies of

	Al-Mustaqbal University / College of Engineering & Technology	12
	(Chemical Engineering and Petroleum Industries Department)	
	Class (4th)	
	Subject (Corrosion Engineering) / Code (CES.R.439)	
	Lecturer (1)	
	1st/2nd term – Lecture No. & Lecture Name (corrosion)	

action in cell converts

electrochemical 1791. A galvanic chemical energy into electrical energy. **Cathode** : One of the two electrodes in an electrolytic cell represented as a **_positive terminal_** of a cell. Reduction takes place at the cathode and electrons are consumed. Example, carbon electrode in a battery,

Examples of cathodic reactions are

$H^+ + e^-$ $1/2\ H_2$

$Cu^{+2} + 2e^-$ Cu

$Fe^{+3} + e^-$ Fe^{+2}
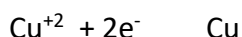
Anode: One of the two dissimilar metal electrodes in an electrolytic cell, represented as the **_negative terminal_** of the cell. Electrons are released at the anode, which is the more reactive metal. For example, in a battery, zinc casing acts as the anode.
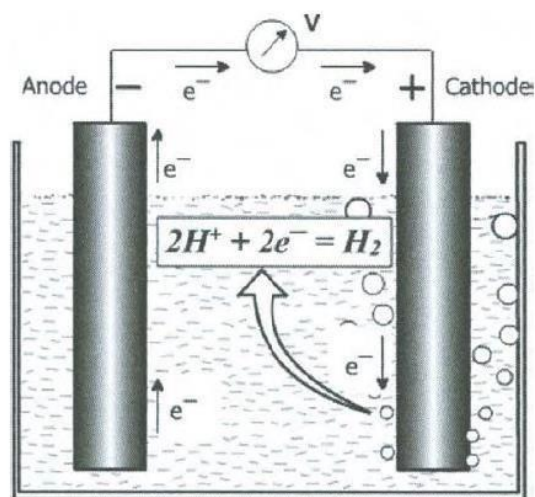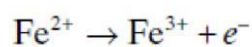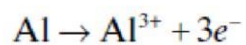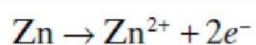
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(Chemical Engineering and Petroleum Industries Department)
Class (4ᵗʰ)
Subject (Corrosion Engineering) / Code (CES.R.439)
Lecturer (1)
1ˢᵗ/2ⁿᵈ term – Lecture No. & Lecture Name (corrosion)

13

$$Zn \rightarrow Zn^{2+} + 2e^-$$

$$Al \rightarrow Al^{3+} + 3e^-$$

$$Fe^{2+} \rightarrow Fe^{3+} + e^-$$

Figure 2.3 Figure showing the reduction of hydrogen in an acid electrolyte

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Class (4ᵗʰ)
Subject (Corrosion Engineering) / Code (CES.R.439)
Lecturer (1)
1ˢᵗ/2ⁿᵈ term – Lecture No. & Lecture Name (corrosion)

Cations are ions that migrate toward the cathode

Anions are ions that migrate toward the anode